FINE CHANNEL DEVICE AND A CHEMICALLY OPERATING METHOD FOR FLUID USING THE DEVICE

[0001] The present invention relates to a fine channel device having a fine channel for conducting a chemical reaction, forming droplet or analysis, in particular, a fine channel device suitable for mixing or a chemical reaction of fluid fed into the fine channel, and solvent extraction or separation or recovering a catalyst from a product, and a chemically operating method using such fine channel device.

[0002] In recent years, research for a chemical reaction by using a fine channel device comprising a glass substrate of several cm square provided with a fine channel having a length of several cm and a width and a depth of from sub-μm to several hundred μm wherein fluid is fed to the fine channel, has been noted. It is reported that in such fine channel, a rapid diffusion of molecules takes place due to effects of a short diffusion distance of molecule and a large specific interfacial area in a fine space whereby a very efficient chemical reaction can be conducted without a special stirring operation, or a compound obtained by a chemical reaction can rapidly be extracted or separated by a solvent extraction/separation method from a reaction phase to an extraction phase whereby a side reaction which may occur subsequently can be suppressed (see, for example, a non-patent document 1: "Fast and high conversion phase-transfer synthesis exploiting the liquid-liquid interface formed in a microchannel chip" by H. Hisamoto et al., Chem. Commun., published in 2001, pages 2662-2663). Here, the fine channel means generally a channel having dimensions of 50-300 μm in width and 10-100 μm in depth.

[0003] In the technique described in the above-mentioned document, a Y-letter like fine channel as shown in **FIG. 1** is used. An aqueous phase **1** in which a raw material is dissolved and an organic phase **2** are introduced into the fine channel to cause a chemical reaction at the fluid boundary **3** of aqueous and organic phases formed at a Y-letter like confluent portion. The Reynolds number is generally less than 1 in a channel of microscale, and therefore, a laminar flow as shown in **FIG. 1** is provided unless flow rates are exceptionally increased. Further, since the diffusion time of molecules is in proportion to the second power of the width **9** of the fine channel, the mixing is accelerated by the diffusion of molecules, without positively mixing the reaction liquid, as the width of 9 of the fine channel is made more smaller, whereby a chemical reaction or solvent extraction is apt to occur. The fluid boundary is often called the laminar flow interfacial surface.

[0004] Further, it is generally reported that when a fluid outlet port **12** in the fine channel is formed to have a Y-letter shape as shown in **FIG. 2**, it is easy to separate an aqueous phase and an organic phase. The above-mentioned technique of separating completely the introduced fluid at the fluid outlet port and discharging it, performs very important functions that a chemical reaction or solvent extraction caused by the contact of at least two kinds of fluid in the fine channel is stopped completely at the branch portion of the fine channel, and the fluid fed once into the fine channel can be re-used.

[0005] In fact, however, the position of the fluid boundary is unstable and variable. In a first factor of causing a change of the position of the fluid boundary is due to a change of flow rate per unit time which is caused by a pump for supplying fluid as shown in FIGS. **3**(*a*) and **3**(*b*). This phenomenon will be explained using a Hagen-Poiseuille expression as the theoretical formula showing a pressure loss based on an internal friction of fluid by a laminar flow in a circular tube. In **FIG. 4**(*a*), assuming that fluid flows in a form of laminar flow at a linear velocity u (m/s) **5** in a horizontal circular tube **7** having a diameter d (m) **6**. Then, the pressure loss ΔP (Pa) as a difference of pressures P1 and P2 acting on both end planes **8** of the circular tube is expressed by Formula 1 of the Hagen-Poiseuille formula:

$$\Delta P = P2 - P1 = 32\,\mu L u / d^2 \qquad \text{(Formula 1)}$$

[0006] where μ(Pa·s) represents a viscosity coefficient and L(m) represents a channel length **10**. When two kinds of fluid A (**13**) and fluid B (**14**) flow in a form of laminar flow forming the fluid boundary in the fine channel as shown in **FIG. 4**(*b*), Formula 1 is established to each fluid, and pressure losses ΔP_A and ΔP_B of the fluid A and the fluid B are indicated by Formula 2 and Formula 3, respectively:

$$\Delta P_A = 32\,\mu L u_A / d_A^2 \qquad \text{(Formula 2)}$$

$$\Delta P_B = 32\,\mu_B L u_B / d_B^2 \qquad \text{(Formula 3)}$$

[0007] where μ_A, u_A and d_A represent a viscosity coefficient, a linear velocity **5** and a fluid width **33** of the fluid A, and μ_B, u_B and d_B represent a viscosity coefficient, a linear velocity and a fluid width of the fluid B respectively. Since the fluid A and the fluid B flow in the same fine channel having a channel width D (m) **22**, ΔP_A and ΔP_B are well balanced, and Formula 4 is established:

$$\mu_A{}^u{}_A / d_A{}^2 = \mu_B u_B / d_B^2 \qquad \text{(Formula 4)}$$

[0008] Further, the relation of the linear velocity u (m/s) to a flow rate v (μL/min) is expressed by Formula 5:

$$u = 1.67\times10^{-11}\cdot v/S \qquad \text{(Formula 5)}$$

[0009] where S (m^2) represents a cross-sectional area perpendicular to a flowing direction of fluid. When the above-mentioned relation is substituted into Formula 4, the following Formula 6 is provided:

$$\mu_A v_A / S_A d_A^2 = \mu_B v_B / S_B d_B^2 \qquad \text{(Formula 6)}$$

[0010] where V_A and V_B represent flow rates of the fluid A and the fluid B respectively, and S_A and S_B represent cross-sectional areas perpendicular to a flowing direction of the fluid A and the fluid B respectively. Further, since the cross-sectional area S (m^2) is in proportion to the second power of the fluid width d (m), the following Formula 7 is established:

$$\mu_A v_A / d_A^4 = \mu_B v_B / d_B^4 \qquad \text{(Formula 7)}$$

[0011] Since the fluid A and the fluid B flow in the same fine channel having a channel width D (m), the following Formula 8 is established:

$$D = d_A + d_B \qquad \text{(Formula 8)}$$

[0012] Here, assuming that the viscosity of each of the fluid A and the fluid B does not change. When the flow rate of the fluid A changes to take a larger value, V_A increases and at the same time d_A increases to keep a balance in Formula 7. When d_A increases, d_B becomes smaller and at the same time, v_B becomes smaller because the channel width D is constant. Then, the balance of Formula 7 can be maintained. Accordingly, the position of the fluid boundary varies due to a change of the flow rate per unit time caused